Textural Observations of H_2O Ice II Nucleation and Growth Processes During Phase Transformations Under Hydrostatic and Nonhydrostatic Stress

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Phase transformations among the H_2O ice polymorphs provide excellent model systems for studying the transformation mechanisms of minerals, due to their chemical simplicity, P-T accessibility, and relative ease of fabricating high quality polycrystalline samples. We have continued our investigation of H_2O ice I→II transformation mechanisms under hydrostatic and nonhydrostatic stress conditions, focusing on ice II nucleation and growth processes, and how these changes affect macroscopic transformation behavior. Here we reassess previous findings in light of recent experiments in which we have tested several different sample configurations of polycrystalline ice at T= 158-195 K, P= 150-300 MPa, and $\varepsilon = 10^{-4}$-10^{-6} s^{-1}, in a gas deformation apparatus uniquely equipped for cold temperature (≥77K) experimentation. Due to the large volumetric strain accompanying the ice I→II phase change (≈-20%), we can document the distribution of ice II as displayed by indium-metal replicas of transformed samples, which show detailed topographic relief where ice II inclusions grow at the surface. These replicas show wide variations in the sizes, shapes, densities, and alignments of inclusions with extent of transformation, temperature, and nonhydrostatic stress.

The strain associated with the ice I→II transformation in bulk under nonhydrostatic stress is markedly anisotropic, as most of the volume change is accommodated by shortening in the direction of maximum compressive stress σ_1. At high temperatures (T≥195K), high strain rate ($\varepsilon=10^{-4}s^{-1}$), and P= 200 MPa, partially transformed and deformed samples appear finely banded, where ice II grows as plate-like polycrystalline inclusions oriented normal to σ_1 with aspect ratios of as much as 200:1. This profoundly anisotropic growth may reflect a stress enhancement at the tips of growing inclusions, and localization of latent heat of transformation at the I-II growth interface may also enhance boundary mobility at high growth rates. At lower imposed strain rates, ice II inclusions show far less elongation. In the same temperature and pressure regime as previously described, lower strain rates produce significantly thicker bands of alternating ice I and ice II regions, in which ice II occurs as fine-grained inclusions (≈10-25 μm), elongated and aligned normal to σ_1. At intermediate temperatures (≈172 K), transformation proceeds as small spherical ice II inclusions nucleate and selectively coalesce in planes normal to σ_1, producing elliptical inclusions. At lower temperatures (77-158K) and lower normal stresses, limited nucleation of ice II (about 2-5% of the total volume) occurs just prior to the onset of a shear instability we term transformational faulting, involving localization of ice II in shear zones. The formation of arrays of ice II inclusions inclined to σ_1 precedes the formation of these faults, and are particularly well developed in those samples tested at the higher temperatures in this regime. *En echelon* array development suggests nucleation and growth in response to imposed shear stress interactions between inclusions. We have previously suggested that this type of shear instability may be a physical mechanism responsible for deep earthquake faulting involving mantle silicates, such as olivine→ spinel. Self-organization of shear arrays of inclusions under stress may be the means by which transformation faults nucleate, grow, and produce earthquakes in descending slabs.

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